An Introduction to Solar Energy Design Fundamentals

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J. Paul Guyer, P.E., R.A., Fellow ASCE, Fellow AEI

CEDengineering.com
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Continuing Education and Development, Inc.
22 Stonewall Court
Woodcliff Lake, NJ 07677

P: (877) 322-5800
info@cedengineering.com

An Introduction to Solar Energy System Fundamentals

J. Paul Guyer, P.E., R.A.

Paul Guyer is a registered civil engineer, mechanical engineer, fire protection engineer and architect with 35 years of experience designing buildings and related infrastructure. For an additional 9 years he was a principal staff advisor to the California Legislature on capital outlay and infrastructure issues. He is a graduate of Stanford University and has held numerous national, state and local offices with the American Society of Civil Engineers, Architectural Engineering Institute and National Society of Professional Engineers.

CONTENTS

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1. INTRODUCTION. A solar thermal energy collection system (or "solar system" for short) is defined as a set of equipment that intercepts incident solar radiation and stores it as useful thermal energy to offset or eliminate the need for fossil fuel consumption. Four basic functions are performed by a typical solar system. For this publication, each function is defined within specific sub-systems of a typical solar energy system as illustrated in Figure 1 and discussed below.

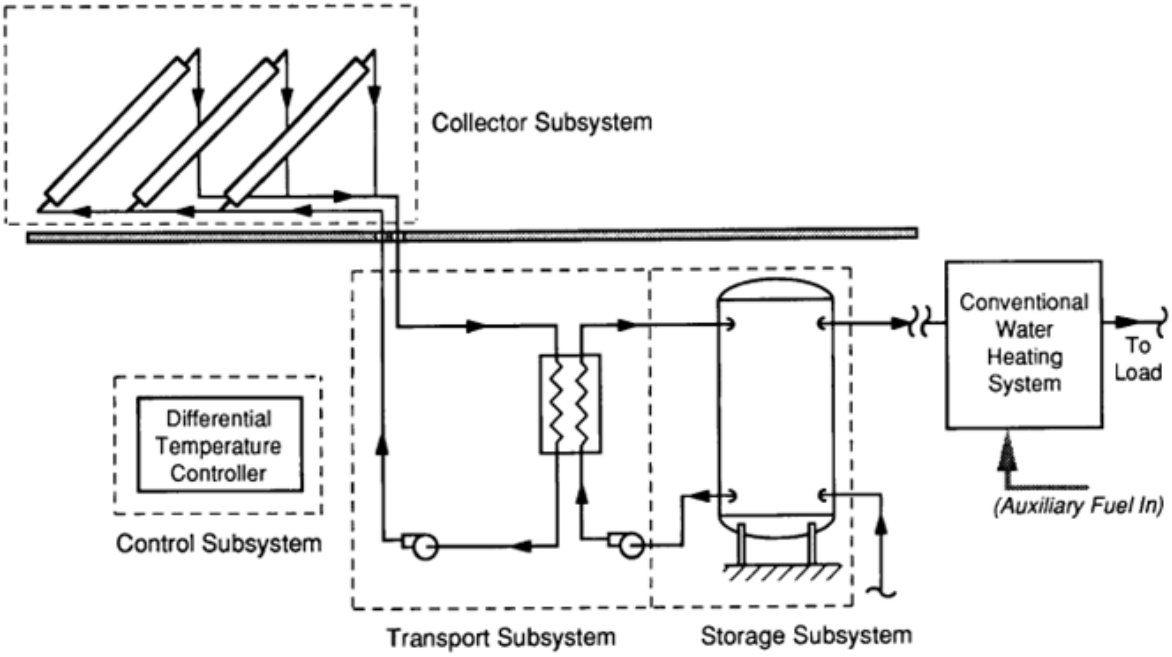

Figure 1
Typical solar thermal energy system

1.1 COLLECTOR SUB-SYSTEM. The collector sub-system intercepts incident solar radiation and transfers it as thermal energy to a working fluid. It is defined as the solar collector, the hardware necessary to support the solar collector, and all interconnecting piping and fittings required on the exterior of the building housing the system.

1.2 STORAGE SUB-SYSTEM. The storage sub-system retains collected thermal energy for later use by the process load. It is defined as the storage tank and its fittings as well as other necessary supports.

1.3 TRANSPORT SUB-SYSTEM. The transport sub-system delivers energy from the collectors to storage. This sub-system is defined to include the heat transfer (or working) fluid, pump(s), the remaining system piping and fittings, an expansion tank, and a heat exchanger (if required).

1.4 CONTROL SUB-SYSTEM. The control sub-system must first determine when enough energy is available for collection. It must then activate the entire system to collect this energy until it is no longer available as a net energy gain. The control subsystem thus consists of electronic temperature sensors, a main controlling unit that analyzes the data available from the temperature sensors, and the particular control strategy used by the controller.

2. SOLAR ENERGY APPLICATIONS

2.1 TYPES OF LOADS. Due to the intermittent and varying amounts of solar radiation available, solar systems used to heat service water are usually not intended to meet the full thermal energy demands of the process being served. For any given thermal load, an integrated system should be designed which consists of both a solar energy collection system and a backup system that can meet the full load requirements. The solar system size and configuration will be a function of the annual or monthly energy loads. It is up to the designer to specify a system that will be expected to provide a given fraction of this load. This is in contrast to the design of a conventional heating, ventilation, and air-conditioning (HVAC) system, which is typically sized to meet an anticipated maximum or design load with no provision to be augmented by another source. For this reason, solar systems are often sized to meet the average expected load. Important characteristics of a load include the amount of energy required, the time of the demand (load schedule), and the temperature range required. Each of these factors is discussed below.

2.2 SERVICE WATER HEATING. Heating domestic hot water and low-temperature process water (both referred to as service water heating) will normally be the most thermally efficient means of using solar energy. The reason is that the demand for thermal energy for these applications is approximately constant during the entire year, with the result that auxiliary fuel savings can be realized over the year. In the preheat configuration, solar heated water is useful at any temperature above that of the incoming water. An additional benefit is that, when preheating process hot water, thermal energy may be delivered at a relatively low temperature, which increases the efficiency of the solar collection process.

3. BASIC MATERIAL CONSIDERATIONS IN SOLAR ENERGY SYSTEMS. The designer should be alert to fundamental material problems that can occur with solar energy systems, and careful attention must be given to the materials and fluids used. Large temperature fluctuations, severe ambient weather conditions, and the variety of possible fluids and metals that can come in contact with each other are often a cause of system failure. Some of the basic issues that must be addressed are discussed briefly below.

3.1 METALLIC CORROSION AND EROSION. Common causes of corrosion include the presence of dissimilar metals (galvanic corrosion), the presence of dissolved oxygen, or fluids with a chemical composition that adversely affects the wetted metal surface. Corrosion may be minimized in solar systems by avoiding dissimilar metals, decreasing the amount of available dissolved oxygen, and treating particularly corrosive fluids with inhibitors. (However, when using a non-toxic fluid, inhibitors should be avoided since they require considerable maintenance and often become mildly toxic upon degradation). Metallic erosion can occur in the system piping if excessive fluid velocities occur. For the copper piping required for solar systems designed under this guidance, a velocity limit of 5 feet per second is to be used. Maximum allowable fluid velocities are dependent upon the type of metal used. Correct pipe sizing and analysis of fluid flow paths should be used to avoid this problem.

3.2 SCALING. Scaling commonly refers to mineral deposits, such as calcium and magnesium compounds, that collect and adhere to pipe interiors and equipment. Scaling is promoted in systems by increased temperatures, high mineral concentrations and high (alkaline) pH levels. The result of scaling is flow restriction, high fluid velocities, and a decreased heat transfer rate. Scaling problems are most often associated with poor-quality water supplies and can be avoided by proper analysis and treatment of fluids to be used in the system.

3.3 THERMAL EXPANSION. Differences between thermal rates of expansion for dissimilar materials often cause problems throughout a solar system. This publication addresses the thermal expansion issue for locations in the system where most problems occur.

4. COLLECTOR SUB-SYSTEM

4.1 DEFINITION. The collector sub-system includes the collectors and support structure, and all piping and fittings required to reach a common heat transfer fluid inlet and outlet. For roof-mounted structures, this sub-system includes all components above the roofline.

4.2 SOLAR COLLECTORS

4.2.1 OPERATION. A solar collector is a device that absorbs direct (and in some cases, diffuse) radiant energy from the sun and delivers that energy to a heat transfer fluid. While there are many different types of collectors, all have certain functional components in common. The absorber surface is designed to convert radiant energy from the sun to thermal energy. The fluid pathways allow the thermal energy from the absorber surface to be transferred efficiently to the heat transfer fluid. Some form of insulation is typically used to decrease thermal energy loss and allow as much of the energy to reach the working fluid as possible. Finally, the entire collector package must be designed to withstand ambient conditions ranging from sub-zero temperatures and high winds to stagnation temperatures as high as 350 degrees F (177 degrees C).

4.2.2 COLLECTOR TYPES. The three major categories that have been used most often are flat-plate glazed collectors, unglazed collectors, and evacuated tube collectors. A general description of each collector type and its application is given below.

4.2.2.1 FLAT-PLATE. Flat-plate solar collectors are the most common type used and are best suited for low temperature heating applications, such as service water and space heating. These collectors usually consist of four basic components: casing, back insulation, absorber plate assembly, and a transparent cover. The absorber panel is a flat surface that is coated with a material that readily absorbs solar radiation in the thermal spectrum. Some coatings, known as "selective surfaces", have the further advantage of radiating very little of the absorbed energy back to the environment. Channels located along the surface or within the absorber plate allow the working fluid to circulate. Energy absorbed by the panel is carried to the load or to storage by the fluid. The absorber panel is encased in a box frame equipped with insulation on the back and sides and one or two transparent covers (glazing) on the front side. The glazing allows solar radiation into the collector while reducing convective energy losses from the hot absorber plate to the environment. Similarly, back insulation is used to reduce conductive energy loss from the absorber plate through the back of the collector.

4.2.2.2. UNGLAZED. Unglazed collectors are the least complex collector type and consist of an absorber plate through which water circulates. This plate has no glazing or back insulation. These collectors are often made of extruded plastic because they are designed to operate at relatively low temperatures. Since they are not thermally protected, these collectors should be operated only in warm environments where lower thermal losses will occur. Swimming pool heating is the most common use of unglazed collectors.

4.2.2.3 EVACUATED TUBE. Evacuated tube collectors are best suited for higher temperature applications, such as those required by space cooling equipment or for higher temperature industrial process water heating. Convective losses to the environment are decreased in this type of collector by encapsulating the absorber and fluid path within a glass tube that is kept at a vacuum. Tracking mechanisms and/or parabolic solar concentrating devices (simple or compound) are often used, resulting in somewhat higher equipment costs.

4.2.3 COLLECTOR EFFICIENCY AND PERFORMANCE.

4.2.3.1 DEFINITIONS. Collector efficiency is defined as the fraction of solar energy incident upon the face of the collector that is removed by the fluid circulating through the collector. Several parameters are defined as follows:

T_i = heat transfer fluid inlet temperature

T_a = ambient air temperature

I = solar irradiance on the collector

A_c = solar collector surface area

F_R = collector heat removal factor, a dimensionless parameter describing the ratio of actual energy gained by the collector to that which would be gained, in the limit, as the absorber plate temperature approaches the fluid inlet temperature. This value is similar to a conventional heat exchanger's effectiveness.

U_L = overall heat loss coefficient. This factor describes the cumulative heat transfer between the collector and the ambient surroundings.

t = transmittance of the glazing.

a = absorption coefficient for the absorber plate. Note that this value varies with wavelength. A selective surface is one that absorbs short wavelength solar radiation very well while emitting longer wavelength thermal radiation poorly.

4.2.3.2 EFFICIENCY PARAMETERS. The efficiency of a given solar collector will vary greatly with ambient temperature, storage tank temperature, and the amount of solar insolation available. For this reason, each type of collector will perform best under different select conditions. Two parameters are required to describe the efficiency of a collector. The first is commonly referred to as $F_R$ta. This factor includes the product of the glazing transmittance and the absorption coefficient and is related to the optical efficiency of the collector. It takes into account reflection losses both through the cover glazing and those due to imperfect absorption by the absorber plate coating. For liquid collectors, the fluid flow rate and collector insulation have very little effect on this factor. The second factor is related to the thermal losses from the collector to the surrounding environment. The product of the collector heat removal factor and the overall heat loss coefficient, F_RU_L, is used to account for the thermal resistance characteristics of the collector. Usually, the fluid circulating through the collector is hotter than the ambient temperature around the collector. This condition means that solar radiation absorbed by the collector can follow two paths. One path is from the absorber plate to the circulation fluid. The second path is from the absorber plate to the surrounding environment. The absorbed solar radiation will be divided according to the temperature differences of each path and the relative thermal resistances. For a given process, these temperature differences normally cannot be controlled. Therefore, the thermal resistances of each path must be considered. The resistance from the absorber plate to the circulation fluid should be as small as possible (i.e., a good thermal bond should be made between the fluid circulation tube and the absorber plate). It then follows that the resistance between the absorber plate and the surrounding environment should be as large as possible.

4.2.3.3. COLLECTOR ENERGY BALANCE. The collector parameters described above allow an energy balance to be expressed as:

> Energy Collected = Solar Energy Absorbed - Thermal Energy Losses to the Environment

The energy balance can be written in a simple equation form using the efficiency parameters described above:

$$\text{Energy Collected} = (F_{Rta})(I)(A_c) - (F_R U_L)(A_c)(T_i - T_a) \qquad \text{(Eq. 1)}$$

Equation 1 shows that heat losses to the environment are subtracted from the net solar radiation transmitted into, and absorbed by, the collector. Assuming that the efficiency parameters are fixed for a given collector model, the main factors that affect the amount of energy collected are I, T_i, and T_a. The geographical location and the season dictate the weather variables I and T_a. The type of process load and system configuration determines the relative circulation fluid temperature, T_i.

4.2.3.4 COLLECTOR EFFICIENCY PLOT. Equation 1 can be rewritten as a dimensionless "efficiency" equation by dividing both sides by the product of I and A_c:

$$\text{Collector Efficiency} = F_{Rta} – F_R U_L (T_i - T_a) / I \qquad \text{(Eq. 2)}$$

Note that this efficiency equation is dependent on only one variable that is a combination of I, T_i, and T_a. This allows it to be graphed in a straightforward manner. Figure 2 is an example of a typical collector efficiency plot. Optical losses are shown as a constant decrease in collector performance, while thermal losses increase as $(T_i - T_a)/I$ increases. The values of F_{Rta} and F_{RU_L} can be determined from this type of plot. F_{Rta} corresponds to the intercept value where the collector efficiency curve crosses the vertical graph axis. F_{Rta} is a dimensionless variable with a value between 0 and 1. F_{RU_L} is calculated by dividing F_{Rta} by the intercept value on the horizontal axis. (It is the negative slope of the plotted line). F_{RU_L} has units of Btu per square foot per hour per degree F.

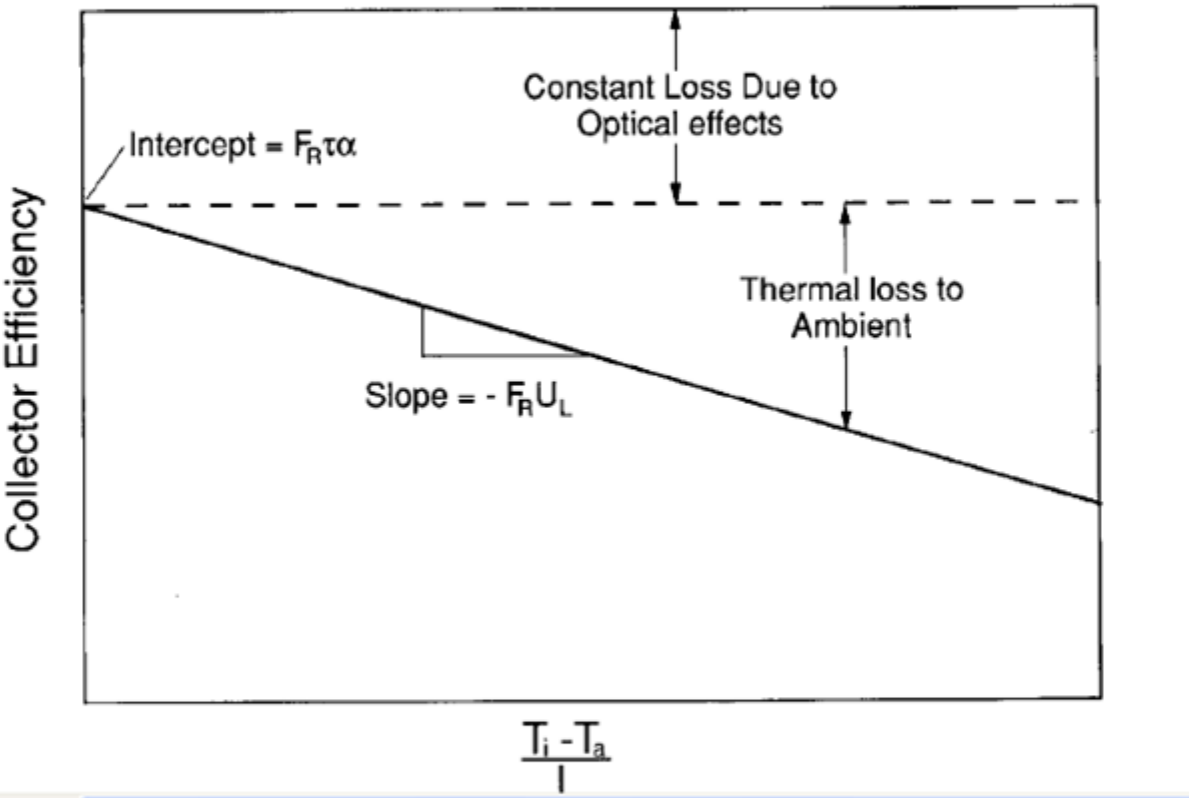

Figure 2
Typical collector efficiency curve

4.2.3.5 PERFORMANCE OF VARIOUS COLLECTOR TYPES. Figure 3 shows why collector efficiency is not always a good indicator of overall collector performance. On any given day, a solar collector can operate over a wide range of efficiencies as the solar radiation, ambient temperature, and heat transfer fluid temperature change. When radiation levels are low early in the day, the efficiency of the collector approaches zero.

As solar radiation levels increase, the collection efficiency increases until it reaches some maximum level. It will then decrease as the solar radiation and ambient temperature decrease at the end of the day. Because of the variable position of the sun, collectors must be oriented so that they are exposed to an acceptable amount of solar radiation throughout the year. Proper collector orientation and tilt values depend on the specific application and system type. Each collector type operates most efficiently in a certain region of the plot, which corresponds to different operating conditions or applications. For example, the unglazed collector works very well under conditions of high solar radiation levels and small temperature differences between the collector fluid and the outdoor temperature (this condition corresponds to the left-hand side of plot). Glazed collectors are better insulated from the outdoor environment and are therefore less sensitive to the solar radiation level and outdoor temperature (shaded region of plot). Evacuated tube collectors are the best insulated of the three types, and will outperform the others at higher operating temperatures (right-hand side of plot). In general, the left-hand side of the plot corresponds to low temperature applications such as swimming pool heating, and the shaded region to service water heating and building space heating. The right-hand side is most applicable to high-temperature processes such as space cooling. An ideal collector is illustrated at the top of the plot, with $F_R$ta equal to one and F_RU_L equal to zero.

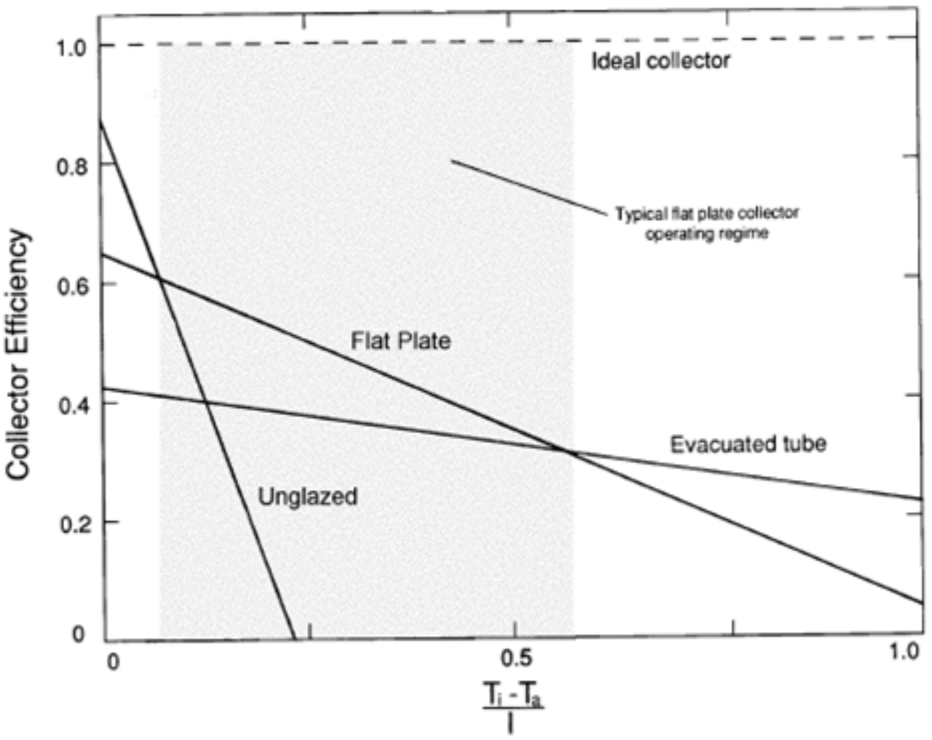

Figure 3
Typical solar collector efficiency plots

4.2.3.6 PERFORMANCE RATINGS. The established test for defining the efficiency parameters of solar collectors is ASHRAE Standard 93. This test is performed by independent laboratories and should be available from collector manufacturers.

4.3 COLLECTOR ARRAY. Individual collectors are normally connected together into groups called "banks". These banks are then piped together to form the complete collector array. Proper sizing of these banks is required to maintain uniform flow throughout the collector array. For efficient system performance, the flow must be balanced throughout the entire array.

4.4 ARRAY SUPPORT STRUCTURE

4.4.1 PURPOSE. A support system is required for the following reasons.

4.4.1.1 SECURE THE COLLECTORS in the correct orientation for maximum solar gain.

4.4.1.2 WITHSTAND THE VARIOUS structural and thermal loads imposed upon the array.

4.4.1.3 RESIST THE IMPACT of environmental deterioration.

4.4.1.4 BE AS LIGHTWEIGHT and inexpensive as possible.

4.4.2 TYPES. <u>There</u> <u>are</u> <u>two</u> basic types of support structures: roof-mounted and ground-mounted. Roof-mounted structures are the most common and are preferred over ground-mounted structures, to avoid vandalism and aesthetic problems. Ground mounting may be necessary where there is insufficient solar access at the roof level and in retrofit situations where the roof cannot support the array or proper access to the roof for piping and sensor wiring is not available. Flat roofs require rack-type structures that are heavier and more costly than the type of structure normally used to mount collectors on sloped roofs. However, rack-mounted collectors on flat roofs are usually easier to service.

4.4.3 STRUCTURAL CONSIDERATIONS. One of the most important issues addressed by structural codes is the design load. Many loads are imposed on a collector array, including dead and live loads; those imposed by the environment, such as wind, snow and seismic loads; and thermal loads caused by the effects of temperature extremes and changes. Wind loads (along with snow loads at some locations) have, by far, the most significant effect on the structure. Dead loads are defined as those attached permanently to the array structure. Live loads are those applied to the array structure temporarily, other than wind, seismic and dead loads (a maintenance worker, for example). The combination of these loads at any instant must be accommodated by the structural design. Local building codes usually prescribe the design load combination to be used. The design and construction of support structures is usually governed by local building and structural codes that are often adapted from nationally recognized U.S. codes. These codes establish the design criteria to insure structural safety and integrity over the expected life of the system.

4.4.4 MATERIAL CONSIDERATIONS. The materials chosen for the array structure must also be able to withstand environmental degradation. Oxidation, caused by humidity and precipitation, affects all metallic surfaces to varying degrees. Aluminum is required for the array support structure because the oxide layer that forms on the surface when it is exposed to moisture protects it from further degradation. Often, aluminum is anodized to provide a controlled layer of oxidation. The use of steel would require a coating system to be applied and maintained, which adds to the system lifecycle cost. The effect of temperature changes must also be taken into account for lengthy structures, especially the difference in thermal expansion between the various types of metals used in solar systems. System piping, which is usually copper, expands at a different rate than the aluminum structure.

4.4.5. COLLECTOR SUB-SYSTEMS (LESSONS LEARNED)

4.4.5.1 COLLECTORS. The single glazed, flat-plate, selective surface collector has proven to be the most reliable and best suited for service water heating needs. Although reflector systems are sometimes advocated to increase the insolation on a collector, they can seldom be justified because they must be cleaned, adjusted, and maintained, and can add a large capital expense. Similarly, strategies involving seasonal collector tilt adjustment are to be avoided. Problems also have arisen with evacuated tube collectors due to thermal expansion and improper fluid flow. The interior construction quality of flat plate collectors remains an issue. Problems such as poor absorber plate/fluid path bonding and improper allowance for absorber plate expansion have been observed. Some collectors have not performed as advertised due to atypical flow rates used during testing and degradation of collector components. Outgassing from insulation and binder materials also remains an issue.

4.4.5.2 ARRAYS. The most common problem with collector arrays is that they do not achieve balanced flow. Shading of the collectors by other collectors and nearby objects must be avoided. Some systems have experienced leaks because thermal expansion was not considered, or improper design methods were used in allowing for thermal expansion.

4.4.5.3 ARRAY SUPPORT*.* Most support structure problems have been associated with material maintenance and aesthetics rather than structural integrity.

5. STORAGE SUB-SYSTEM

5.1 DEFINITION AND OPERATION. The intermittent nature of solar energy establishes a need for a sub-system capable of storing energy for 1 to 2 days. The most common method of doing this for an active solar system is through the use of a water-filled tank that obtains thermal energy from the collector loop either directly or through a heat exchanger. The water from the storage tank then functions as a source of preheated water to an auxiliary heater or boiler that adds the necessary energy to raise it to the required temperature. In some cases, the storage medium may be heated above the required temperature, and a mixing valve can be used to reduce the storage fluid to the desired temperature before it reaches the load. The systems discussed in this manual assume a storage requirement of approximately 1 day.

5.2 STORAGE MEDIA. The most effective and trouble-free storage medium is water. For this reason, systems discussed in this manual will assume water-based storage.

6. TRANSPORT SUB-SYSTEM

6.1 PURPOSE. The fluid transport sub-system is required to maintain efficient transport of thermal energy from the collectors to the storage tank. Fundamental design decisions regarding freeze protection, corrosion resistance, control strategies, and fluid toxicity issues will be made with respect to this part of the solar energy system. The transport subsystem consists of all fluid piping on the interior of the building, a heat transfer fluid, heat exchanger, expansion tank, pumps, and various types of valves and fittings.

6.2 FREEZE PROTECTION

6.2.1 PURPOSE. Freeze protection is required in any climate that can experience temperatures less than 32 degrees F (0 degrees C). However, collectors may be subjected to sub-freezing temperatures (due to radiant heat transfer to the sky on a clear night) even when ambient temperatures are as high as 38 degrees F (3 degrees C).

6.2.2 STRATEGIES. Common freeze protection strategies include the use of an antifreeze fluid in the collector loop, or to drain all exposed piping when freezing conditions exist

6.2.3. STAGNATION AND OVERHEAT PROTECTION. Stagnation is a condition that may occur when the system is deactivated while fluid is contained in the collectors during periods of solar insolation. For example, on a sunny day stagnation temperatures in a flat-plate collector can exceed 350 degrees F (177 degrees C), leading to vaporization of the transport fluid within the collector and excessive pressure build up in the system piping. In the case of a closed-loop system, it is important to ensure that all components in the collector loop can withstand these temperatures and pressures. A pressure relief valve and an expansion tank should also be used to protect the system components and control pressures.

6.3 HEAT TRANSFER FLUIDS

6.3.1 DEFINITION. The heat transfer fluid is contained in the collector loop. Selection of the proper fluid is critical, since certain fluid properties can cause serious corrosion problems or degrade performance. Only water and propylene-glycol/water solutions are considered.

6.3.2 TYPES OF FLUIDS

6.3.2.1 WATER. As a heat transfer fluid, good quality water offers many advantages. It is safe, non-toxic, chemically stable, inexpensive, and a good heat transfer medium. Two drawbacks include a relatively high freezing point and a low boiling point. Excessive scaling may occur if poor quality water is used.

6.3.2.2 GLYCOLS. Propylene or ethylene glycol is often mixed with water to form an antifreeze solution. Propylene glycol has the distinct advantage of being nontoxic, whereas ethylene glycol is toxic and extreme caution must be used to ensure that it is isolated from any potable water. For this reason, uninhibited USP/food-grade propylene glycol and water solution will be specified for any solar preheat system that requires an antifreeze solution.

6.4 HEAT EXCHANGERS

6.4.1 PURPOSE. Heat exchangers are used to transfer thermal energy between fluids while keeping them separate to prevent mixing or to maintain a pressure difference between fluid loops.

6.4.2 TYPES. Heat exchangers are available in a wide variety of sizes and configurations. The primary concern is the chemical composition of the fluids used in the heat exchanger. The fluid determines whether a single- or double-isolation heat exchanger will be necessary. Double-isolation heat exchangers are required whenever there is possible contamination of the potable water supply by a toxic collector loop fluid. Also important is the heat exchanger location with regard to the storage tank. Immersion-type heat exchangers are located within the storage tank and operate by forced convection on the tube side and natural convection on the tank side. Single isolation external heat exchangers are separate from the tank and require two pumps to circulate the fluid on both the hot and the cold side. For solar systems, increased performance due to forced convection heat transfer in external heat exchangers usually offsets the additional cost of operating a second pump. For this reason, external, forced convection heat exchangers are usually used for systems designed under this guidance.

6.4.3 CONFIGURATIONS. Of the many configurations of heat exchangers possible, two have found widespread use with liquid-based solar systems. The most common heat exchanger used in past solar projects is the shell-and-tube configuration, in which an outer casing or shell encloses a tube bundle. These units are usually thermally efficient, compact, reliable and easy to maintain and clean. Shell-and-tube exchangers typically provide only single isolation. The other commonly used heat exchanger is the plate or plate-and-frame type. This type of exchanger is becoming increasingly popular with designers and contractors. It can afford single- or double-wall protection, provide high performance, use superior materials, have low volume and surface area, and be easily enlarged or reduced if the system size is changed. Most heat exchangers are available with copper fluid passages, and many plate-type exchangers have stainless steel passages.

6.4.4 HEAT EXCHANGER PERFORMANCE. A common measure of heat exchanger performance is its effectiveness. Effectiveness is defined as the ratio of the actual rate of heat transfer to the maximum possible. Two common problems, fouling and freezing, can decrease heat exchanger effectiveness. Fouling is the term used for scale and corrosion that collects in the passageways. Fouling decreases the amount of energy transferred and is often taken into account in heat exchanger analysis. The amount and rate of fouling to be expected depend on the fluids and materials used. Heat exchangers can freeze in systems containing antifreeze due to reverse thermosiphoning or improper control.

6.4.5 EFFECT ON SYSTEM PERFORMANCE. The use of heat exchangers can only serve to degrade the performance of the solar energy system. However, since they are required for most systems, their impact on performance should be understood. Although system performance suffers by only about 10 percent for heat exchangers with effectiveness values as low as 0.3, the popularity of compact plate-type heat exchangers and their low add-on costs allow the designer to achieve high effectiveness levels with only a slight increase in equipment cost.

6.5 PUMPS. Heat transfer fluids are circulated by pumps. Two circulation pumps are required in the system shown in Figure 1. For the majority of liquid-based solar energy systems, centrifugal pumps with fractional horsepower requirements are used for heat transfer fluid circulation.

6.6 TRANSPORT SUB-SYSTEM (LESSONS LEARNED)

6.6.1 HEAT TRANSFER FLUIDS. To eliminate past problems with fluid maintenance, freeze protection, and corrosion control, a USP/food-grade uninhibited propylene glycol/distilled water mixture is required for systems that need freeze protection and pure water is recommended for systems that do not.

6.6.2 PIPING AND TRANSPORT SUB-SYSTEM MATERIALS. Materials problems with piping include corrosion, erosion, and scaling. Corrosion can be avoided by using flow passages of copper, bronze, brass or other non-ferrous alloys. Pipe erosion and excessive hydraulic noise can be avoided by ensuring that fluid velocities in closed piping systems are kept below 5 ft/s (1.5 m/s).

7. CONTROL SUB-SYSTEM

7.1 PURPOSE AND EXPERIENCES. The control sub-system consists of an electronic control unit, temperature sensors, and interfaces to pumps. A Btu meter may also be installed for system diagnostics and monitoring purposes. Experience with past systems has shown that a major cause of system failure has been control systems that were too complicated and unreliable. Control strategies for solar energy systems should be as simple and reliable as possible.

7.2 CONTROL STRATEGY. Most solar systems use a control strategy known as differential temperature control. Temperature sensors are located on the collectors and at the coolest part (the bottom) of the storage tank. Circulating pumps in the collector and storage loop are simultaneously activated whenever the temperature of the solar collector is a specified level greater than that of the storage tank (typically 15 to 25 degrees F (-9 to -4 degrees C). The pumps are then shut off when the temperature difference falls below another limit (typically 5 to 8 degrees F (-15 to –13 degrees C)). This built in hysteresis helps prevent short cycling of the pumps during start-up as the colder water from the storage tank comes in contact with the hot collector plate.

7.3 DIAGNOSTICS. The control system can contribute to the system's longevity and ease of maintenance by providing remote readings of system parameters such as component temperatures, pump status, and maximum/minimum temperatures. If installed, a Btu meter can measure the flow rate and temperature of fluid delivered to storage in order to calculate the total energy contributed by a system. It is possible for a solar system to be inoperative and yet show no symptoms due to the existence of an auxiliary heat source. The use of built-in diagnostic devices helps prevent this condition from occurring.

8. SOLAR ENERGY SYSTEM PERFORMANCE. To design a cost-effective solar energy system, it is important to understand the difference between collector efficiency and annual system performance. The solar fraction (SF) is the ratio of the energy supplied by the solar system to the total energy required by the process. Figure 4 is a typical plot of solar fraction versus collector area. Note that, for small collector areas, a relatively small increase in collector area leads to a steep increase in solar fraction. As the collector area is increased, however, each additional square foot of collector area yields a smaller increase in solar fraction, until the curve asymptotically approaches a solar fraction of 100%. Another important parameter is the solar load ratio (SLR), which is defined as the ratio of the annual (or monthly) radiation incident on the collector array to the annual (or monthly) energy requirements of the building system. The selection of the optimum collector area for a given building system is ultimately an economic decision, as the cost of additional collector area and system capacity must be weighed against the diminishing return in solar fraction gained.

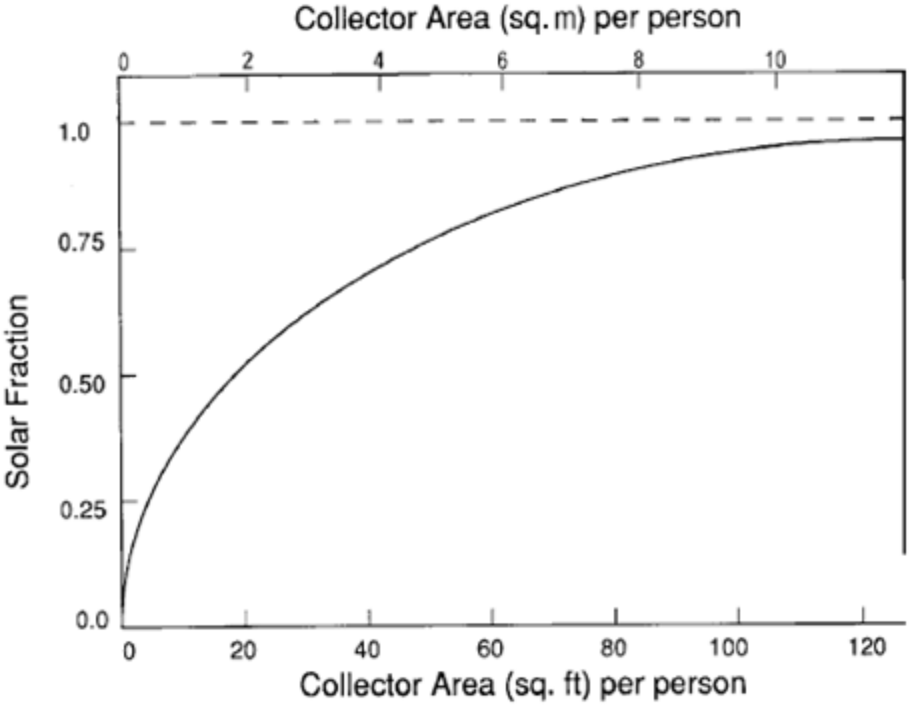

Figure 4
Solar fraction versus collector area

9. SUMMARY

9.1 SERVICE WATER HEATING. Experience, experimental simulations, and economic analyses have shown that the most efficient use of solar energy in military facilities is for loads that use low temperatures on a year-around basis, such as that needed by service water heating. This application yields the best use of energy per square foot of installed collector area and represents the greatest potential for cost-effective solar energy use within the Services.

9.2 STANDARD SOLAR ENERGY SYSTEM. Although fundamental principles for many types of systems have been discussed, the type of system best suited for water heating will use flat-plate, liquid-based collectors, water storage, and a propylene glycol/water solution as the heat transfer fluid. Control systems should use simple differential temperature control with built-in diagnostics. This type of system will be the most reliable and effective in meeting the Services' needs and design/construction practices.